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Tunable and switchable bulk acoustic resonator with graded BST composition

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ABSTRACT

In this paper, we are presenting the results on tunable and switchable graded composition BaxSr1-xTiO3 (x = 0.6 to 0.90) film bulk resonators (FBARs) based on Silicon dioxide/Tantalum oxide Bragg reflectors. The Bragg reflectors can withstand high temperatures of about 800°C during annealing of graded barium Strontium Titanate (BST) film. BST films as well as Bragg reflectors were all deposited by spin on technique. The DC bias-dependent resonance frequency due to electro-restriction of the graded BST film decreases with increasing bias field and the tunability is about 2% for an applied bias voltage of 14 V. The calculated electromechanical coefficient for these resonators increases with applied bias and the maximum value of 12.5% is reached for a bias voltage of 10 V. The maximum quality factor 'Q' for these devices was 80 at a bias voltage of 13 V.

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KEYWORDS
FBAR; graded BST; thin film BAW resonator; switchable; tunable

1. Introduction

Thin film bulk acoustic resonators (FBARs) using aluminum nitride (AlN) and zinc oxide (ZnO) have found widespread use in mobile phones as duplexers and filters because of their small size, low insertion loss, high power handling capability and possibility of integrating with silicon very large scale integration technology [1]. Recently, FBARs with Barium Strontium Titanate (BST) are attracting the attention of many researchers because of their switchable and tunable characteristics [2]. Most of the results published in this area of research are on single composition BST [6–9]. Recently, it has been reported that graded composition $Ba_x Sr_{1-x} TiO_3$ (x = 0.6 to 0.9) gives the opportunity to fabricate temperature independent dielectric constant components with improved piezoelectric constant and over single composition BST [3–5]. In this paper we are presenting the results of switchable/tunable graded BST solidly mounted resonators fabricated on silicon dioxide/tantalum oxide Bragg reflectors on high resistivity silicon substrates.

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2. Sample preparation

The starting wafer was high resistivity (100) silicon with a sheet resistivity of 20 kΩ.cm. The wafer was baked a temperature of 180°C for minutes in a vacuum to dehydrate the surface. Spin on silicon dioxide films obtained by Honey well as spun on these wafers at a spin speed of 3000 rpm for 30 seconds. The wafers were baked at a temperature 180°C for 2 minutes and 280°C for 5 minutes on a hot plate. The thickness of SiO_2 deposited was close to 90 nm. The process was repeated for 2 more layers and the wafer was annealed in a furnace at 800°C for 5 minutes. Tantalum oxide spin-on metalorganic solution procured from Kujundo, Japan was deposited on these wafers at a spin speed of 2000 rpm for 30 secs. The wafers were baked at the same conditions as described for SiO_2 films and the thickness of tantalum oxide was found to be about 90 nm.

A second layer of tantalum oxide was deposited on these wafers and two step annealing was performed. The wafers were then annealed at 800°C for 5 minutes in oxygen and the thickness of tantalum oxide was found to be 180 nm. The process was repeated to achieve 6 layers with alternate layers of silicon dioxide and tantalum oxide. Bottom electrode platinum of thickness 100 nm and titanium 20 nm were deposited by DC magnetron sputtering. The bottom electrodes were patterned using standard photolithographic techniques and ion-milling. BST MOD solution with 60:40 composition was spun on these wafers at a spin speed of 2000 rpm for 30 secs and a two-step baking was performed as explained earlier. The wafer was annealed at a temperature of 800°C for 5 minutes in oxygen environment. The process was repeated for BST MOD composition 75:25 and 90:10. The wafers were finally annealed at a temperature of 800°C for 30 minutes in oxygen.

Figure 1 shows the schematics of cross-section of FBARs with graded BST. Fig. 2 shows the micrograph of fabricated resonator structures with graded BST.

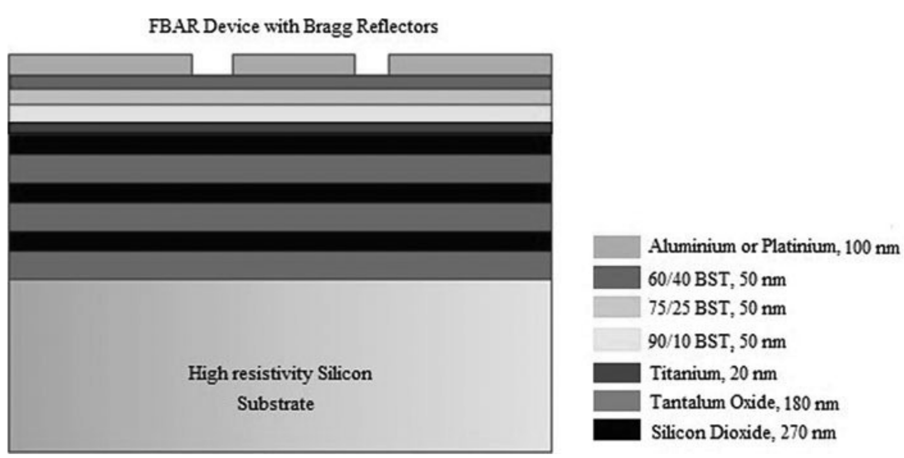

Figure 1. Schematic cross-section of FBAR with graded BST.

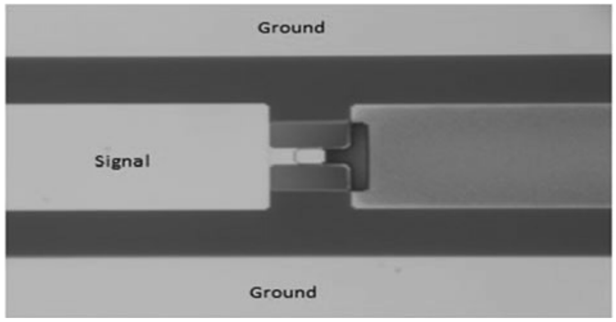

Figure 2. Micrograph of fabricated resonator.

3. Results and discussion

The electrical characterization of the wafers was performed with s-parameter measurements with cascade micro-tech ground-signal-ground probes by mounting the wafer on vacuum check. The measurement system was calibrated with on wafer open, short and matched structures. Fig. 3 shows the variation of scattering parameter S11 with frequency for graded BST FBARs. The FBAR did not show any variation in S11 with frequency for an applied voltage confirming the absence of resonance. With increase in applied voltage due to electro restriction, the notch depth increases. Fig. 3 shows the variation of resonance frequency with applied voltage. The resonant frequency changed from 4.92 GHz to 4.83 GHz and the tunability is about 2%. Fig. 4 shows the Butterworth-Van-Dyke (BVD) equivalent circuit parameters extracted from the measured results using Agilent Technologies ADS circuit simulator for the resonator. The motional inductance L_{m}, capacitance C_{m} and resistance R_{m} are given by the following equations:

$$L_m = \left(\pi^3 \ \upsilon_a\right)/\left(8\, \varepsilon_r\, \varepsilon_o\, Area\, \omega_r\, k_t^2\right), \tag{1}$$

$$C_m = \left(8\, \varepsilon_r\, \varepsilon_o\, Area\, \omega_r\, k_t^2\right)/\left(\pi^3 \ \upsilon_a\right), \tag{2}$$

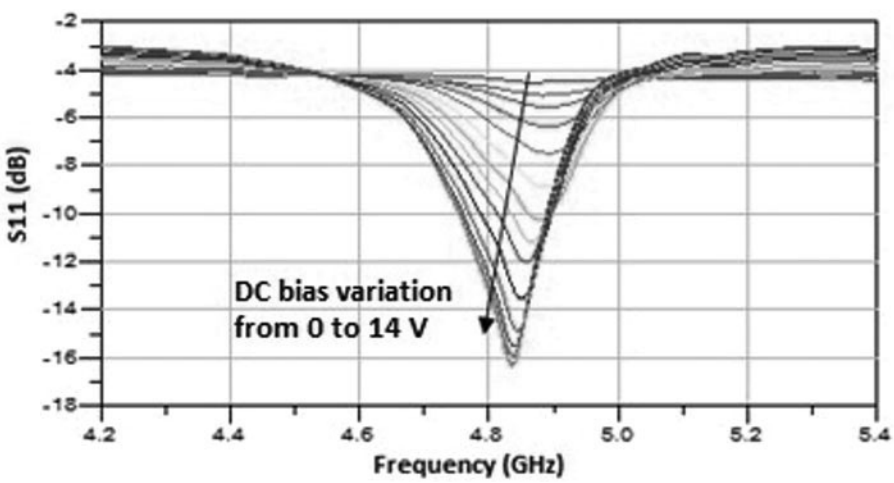

Figure 3. Variation of S11 with frequency for applied bias voltages 0V to 14V.

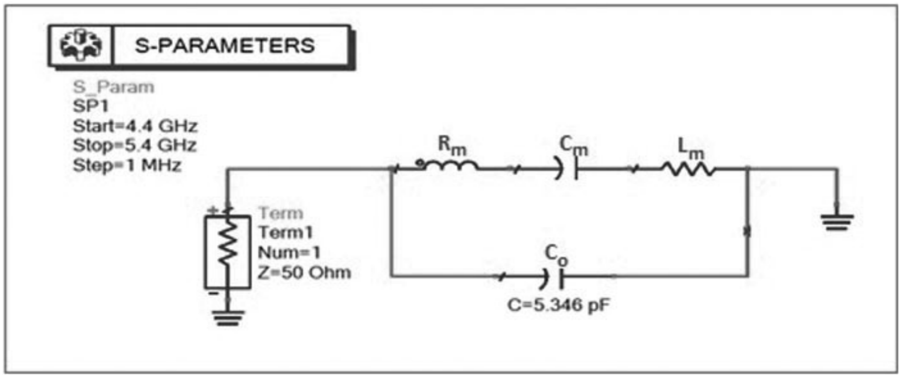

Figure 4. ADS extracted equivalent circuit for the resonator with graded BST resonator.

$$R_m = (\omega_r L_1)/(Q), \tag{3}$$

Where ν_a is the acoustic velocity, (f_r) the resonant frequency, k_t^2 is the electromechanical coefficient, ε_r is the average relative permittivity of BST, ε_o is the permittivity in vacuum and Q is the quality factor of the resonator.

From the extracted parameters, S11 values were simulated using the ADS and the variation of S11 with frequency is shown in Fig. 5 and is in close agreement with Fig. 3.

Figure 6 shows the measured variation of impedance with frequency for the graded BST FBARS. For an applied voltage of 14 volts, the series resonance frequency (f_r) was found to be 4.661 GHz and the parallel resonance frequency (f_a), was 4.921 GHz. The effective electromechanical coefficient ($k^2_{t,\,eff}$) was calculated using Eq. (4) and found to be 12.5% at 13 V.

$$k^2_{t,\,eff} = \pi/4\,(f_a - f_r)/f_r \tag{4}$$

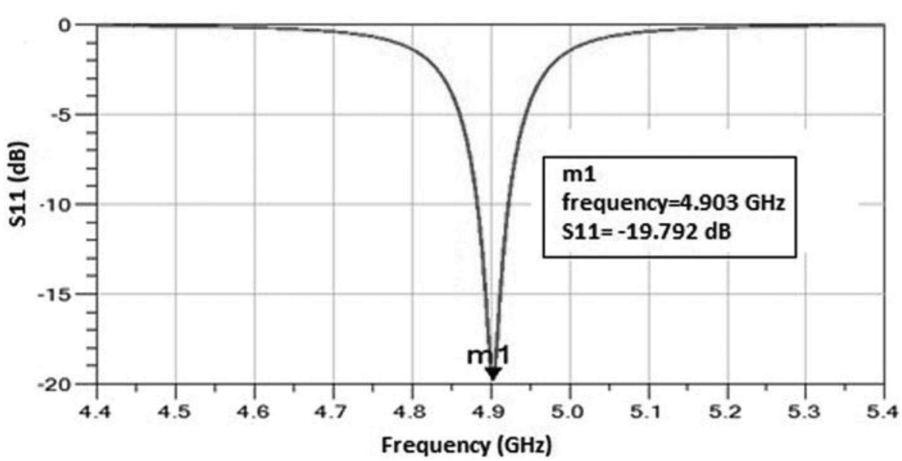

Figure 5. Simulated S11 of the FBAR resonator with graded BST.

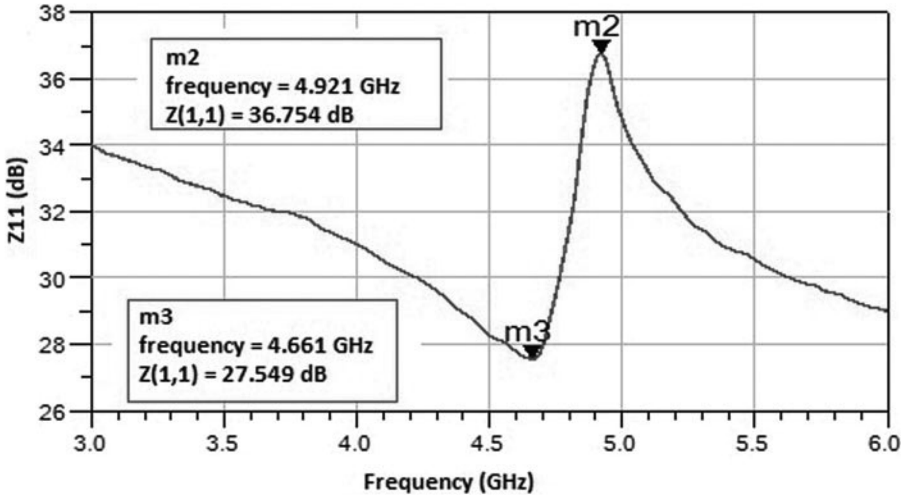

Figure 6. Measured variation of impedance with frequency for graded BST FBARs.

The quality factor 'Q' of resonators were calculated using the following expression:

$$Quality\ factor\ \ (Q) = \ f_{s,p}/2\left|d\Phi_z/df\right|, \tag{5}$$

where $d\Phi_z$ is the impedance phase, $f_{s,\,p}$ is the resonance frequency (series or parallel).

The variation of Q factor at parallel resonance frequency with applied voltage is shown in Fig. 7. The measured quality factor increases with increase in applied voltage initially and remains constant above an applied voltage of 13 V. The highest quality factor obtained was 80 at an applied voltage of 13 V.

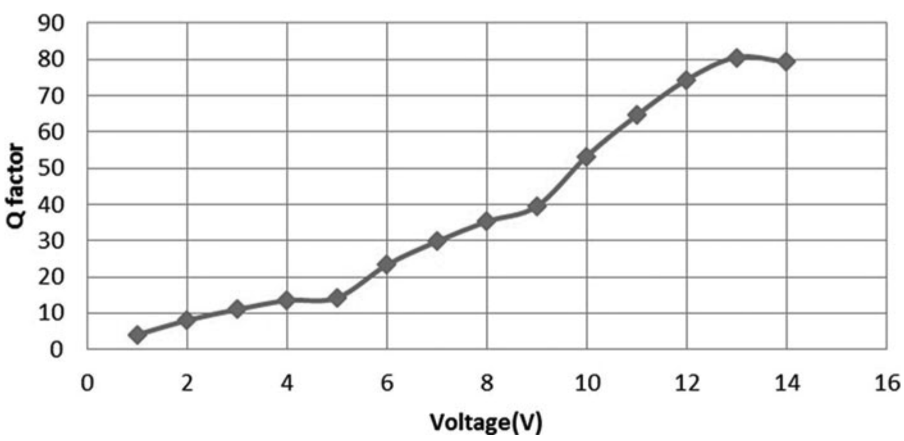

Figure 7. Variation of 'Q' factor with applied voltage for BST resonator.

4. Conclusions

Solidly mounted switchable and tunable FBARs have been fabricated with graded $Ba_x\ Sr_{1-x}TiO_3$ (x = 0.6 to 0.9) by spin-on MOSD technique on high resistivity silicon substrate. Alternate layers silicon dioxide/ tantalum oxide of thickness equal to quarter wavelength deposited by spin-technique are used as Bragg reflectors and this withstands BST processing temperature of 800 C in oxygen atmosphere. The tunability of the resonance frequency was about 2% for an applied DC bias of 14 V. The maximum effective electromechanical coefficient of 12.5% was obtained for these resonators for an applied voltage of 10 V. The quality factor 'Q" of the resonator was found to increase with DC bias voltage and a maximum of 80 was obtained at a bias voltage of 13 V.

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